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Services

Kourou
March 2008

ATV JULES VERNE

Launch Kit

All the space you need

EADS astrium

ATV JULES VERNE
Launch Kit

Content

1. Introduction

The Automated Transfer Vehicle (ATV) is an unmanned expendable space transport vehicle designed for logistic servicing of the International Space Station (ISS).

It provides the capabilities of delivering pressurized and unpressurized cargoes to the Space Station and serves for ISS refueling. Moreover, the ATV system is capable of raising the Space Station orbit (ISS re-boost) in order to counteract a decrease in its orbital altitude due to atmospheric drag and contributes to space station attitude control.

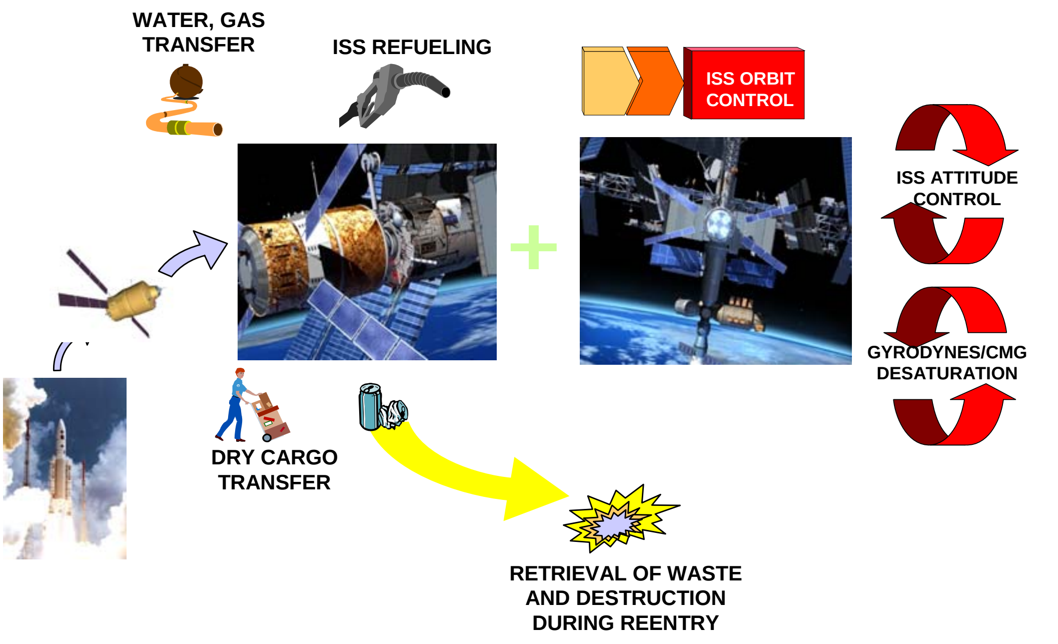
The ATV is launched atop an Ariane 5 vehicle into a viable quasi- circular orbit. Once on orbit, the ATV becomes fully autonomous and performs all the operations until direct docking to the Space Station under the control of the ATV Control Centre (located in Toulouse) and in coordination with the ISS Control Centres (located in Moscow and Houston). It docks to the station precisely and safely and becomes a manned spaceship for a period up to 6 months. After its mission completion, the ATV will de-dock from the station carrying away tons of waste to be disposed.

The first spaceship has been named for “Jules Verne”, the famous novelist and visionary who anticipated many of the 20th century's greatest technological achievements.

2. ATV Mission Overview

The Design Reference Mission of the Automated Transfer Vehicle is to provide support services to the International Space Station (ISS) during six months following its docking to the Russian Service Module (Zvezda). The main mission objectives are:

- Propulsive support to ISS including re-boost, attitude control, CMG (Control Moment Gyro) de-saturation and debris avoidance,
- Delivery of cargo, water and gas, and retrieval of wastes,
- ISS refuelling



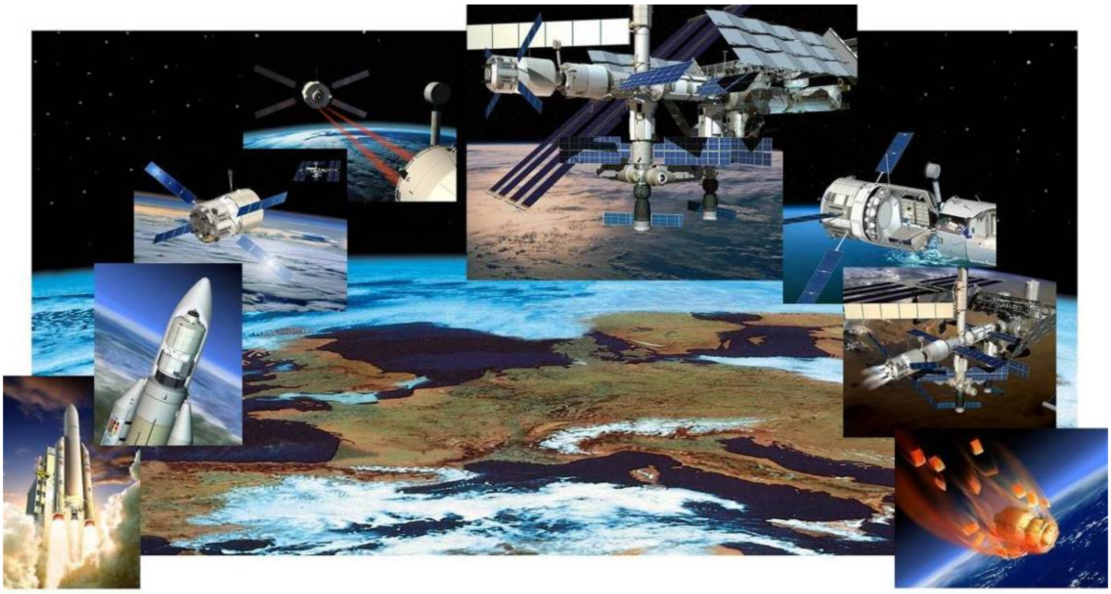
ATV Mission Objectives

ATV safety with respect to the ISS and its crew has been a fundamental driver of the vehicle design, qualification and operations. The safety required is built into the vehicle functional design and supplemented by a dedicated Proximity Flight Safety function. Such a function relies on a segregated computer with the capability to command and execute a Collision Avoidance Manoeuvre (CAM) as an ultimate protective measure.

Being one of the main contributors to ISS servicing, the ATV is required to meet 99.2% of launch availability over a period of 4 days (target availability) as well as 95% probability of successful mission completion starting from vehicle activation at launch count down, and continuing through to atmospheric re-entry.

Each ATV flight includes five main phases:

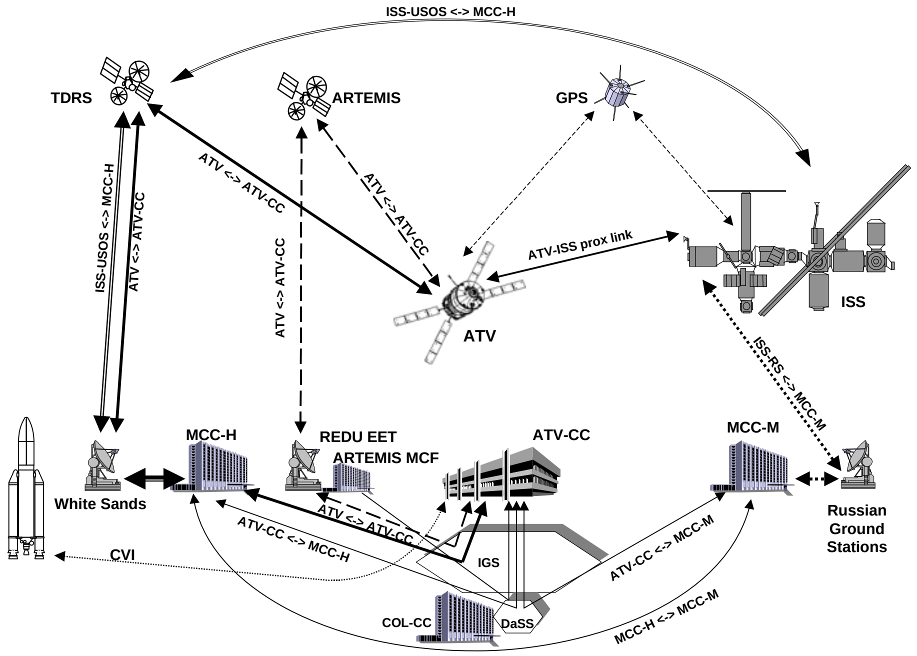
- Launch by Ariane 5 and early in orbit operations
- Orbital flight to reach the ISS orbit (phasing)
- Rendezvous with the station and docking
- The attached phase when the ATV becomes an integral part of the station
- Separation and departure from the ISS, de-orbiting and atmospheric re-entry



To achieve successful completion of all these phases, the ATV performs highly automated operations while remaining operationally flexible to a large extent.

3. Operational Environment

In order to perform its mission, the ATV functions within the operational network that includes the ATV system itself (flight and ground segment), the ISS space and ground segment, Ariane 5 and its related launch site facilities as well as their relevant control centres (Toulouse, Moscow and Houston) and communication systems.



Overview of ATV system related entities

The ATV Control Centre in Toulouse (ATV-CC) is designed to be operational during the entire ATV life cycle (up to 15 years). During all flight phases (free flight and attached) the link with the ground (ATV-CC) is established via the Tracking and Data Relay Satellite System (TDRSS) and ARTEMIS. During attached phases, when ATV is in dormant mode, the link via TDRS/ARTEMIS is activated during a typical 10mn slot per orbit. During proximity operations, the ISS provides data to ATV and also can send some High Level Tele-Commands (HLTC) via the proximity link in case of contingencies.

All the ground commands are issued by the ATV-CC. The CAM (Collision Avoidance Manoeuvre), Resume, and Hold related commands can either be initiated by the ATV-CC or by the ISS crew. During the attached operations (re-boost, refuelling, etc.), the ATV is commanded by the ISS after preparation by ATV-CC and under ATV-CC control.

The GPS system is used for ATV navigation. During phasing and de-orbiting, the absolute navigation is performed on the ground by ATV-CC.

During rendezvous, the relative navigation is performed on-board by the ATV GPS receivers. The ISS GPS measurements are transmitted to the ATV via proximity link so that ATV can compute the relative state vector (Relative GPS, hereafter referred to as RGPS).

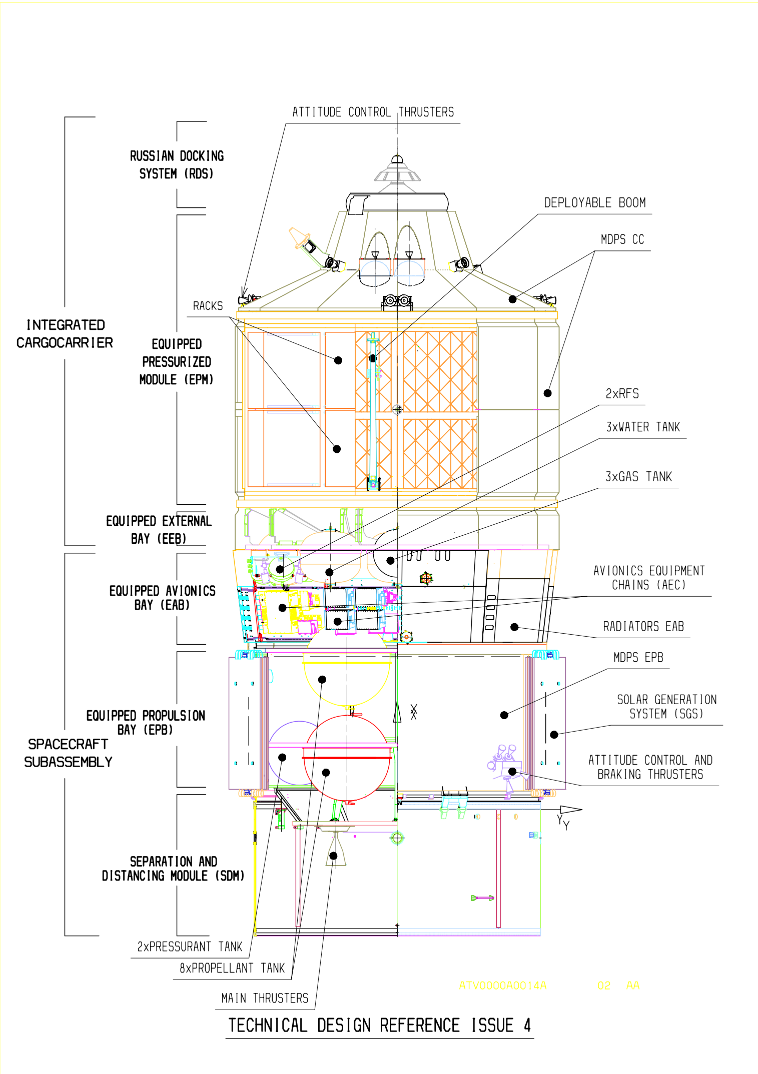
ATV Control Centre in CNES Toulouse

4. ATV Design

The vehicle consists of two principal components:

The **Integrated Cargo Carrier** is sized for transportation of the pressurized cargo items, fluids and gas to the Russian Segment of the ISS and for the ISS refuelling. It contains cargoes dedicated to the Space Station re-supply corresponding to the ATV reference mission under agreement between NASA, Russian Space Agency and ESA. It also serves as a connecting part to the Space Station during the attached phase and enables crew access to a "shirt sleeves" environment via the hatch of the docking system.

The **Spacecraft** is a self-contained module in which most functions and resources enabling conduct of the ATV flight (on-board management, GNC, propulsion, communication, thermal control, power) and for the ISS re-boost are accommodated. It ensures the mechanical interface with Ariane 5 via the Separation and Distancing Module (SDM).



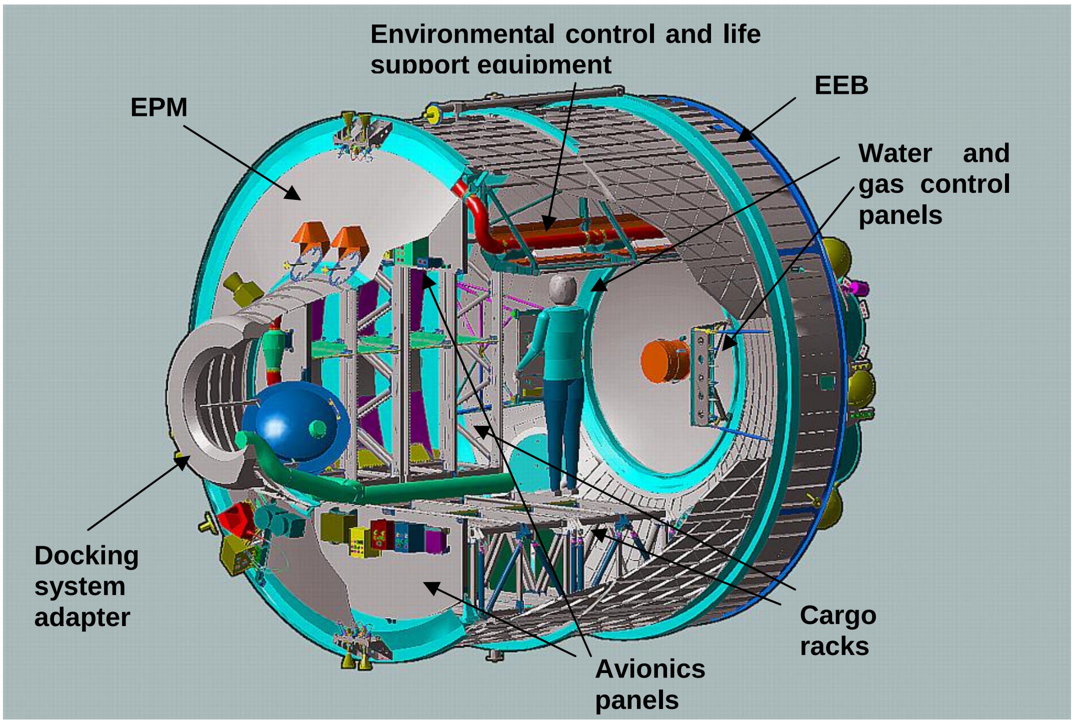
4-1. Integrated Cargo Carrier

The **Integrated Cargo Carrier (ICC)** is composed of:

- a pressurized part defined as the Equipped Pressurized Module (EPM) and,
- a non-pressurized part designated as the Equipped External Bay (EEB).

The Russian Docking System (active part) is mounted on the ICC and enables physical and electrical connection with the Space Station during the attached phase as well as ensuring ISS crew access to the pressurized part of the ICC.

A Micrometeoroids and Debris Protection Subsystem (MDPS) protects both pressurized and non-pressurized parts of the cargo carrier.



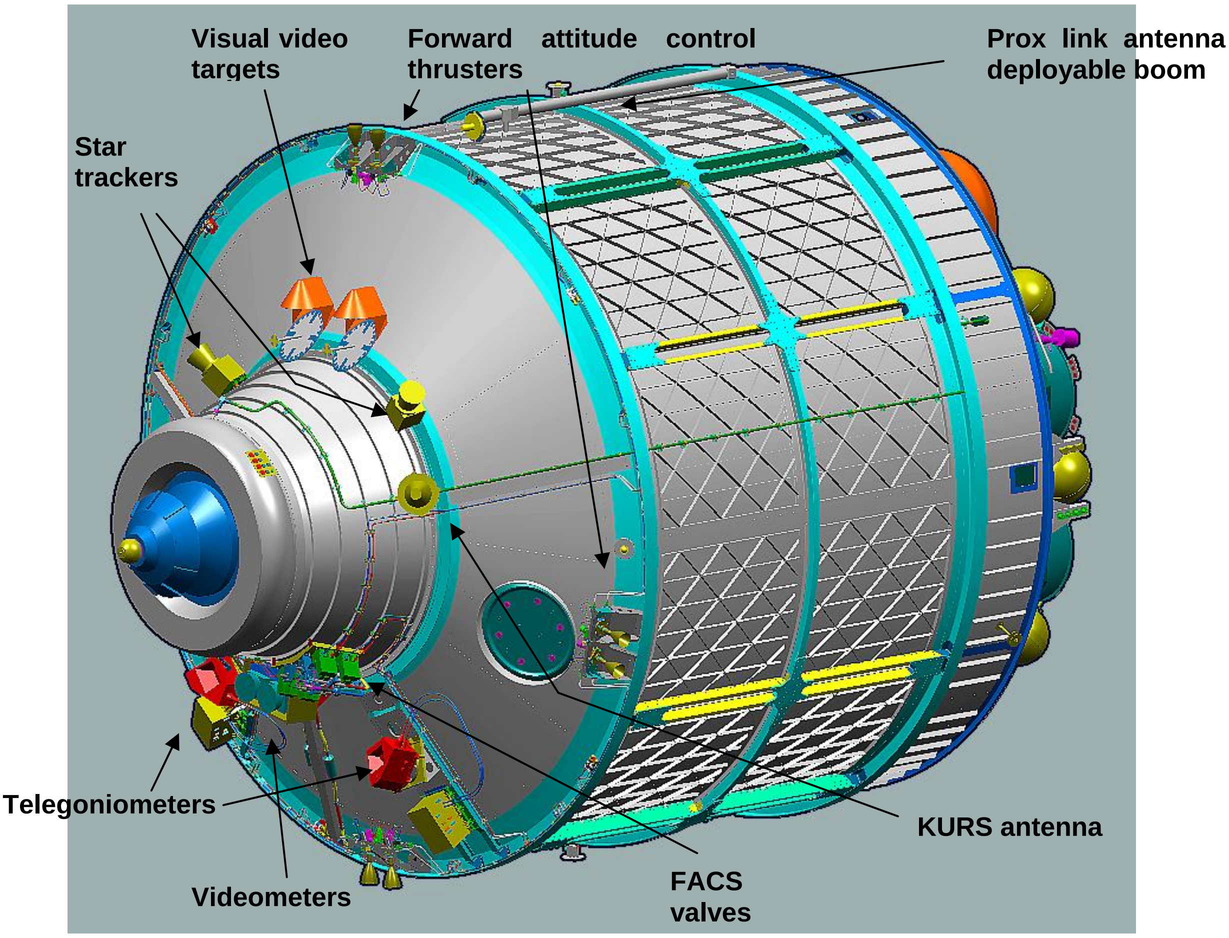
The **Equipped Pressurized module (EPM)** is mainly dedicated to cargo accommodation.

Apart from the dry cargo carried on racks, the EPM houses the following systems and avionics equipment:

- Environmental Control and Life Support (ECLS) equipment including cabin fan, 2 positive pressure relief valves, 2 pressure equalization valves, 3 pressure sensors, smoke detector and lights for internal illumination
- The control panels for water and gas delivery
- The Russian Docking System (RDS) and its avionics,
- The Russian Equipment Control System (RECS) serving for docking and refuelling systems control as well as for power and discrete lines interface with the ISS when ATV is attached to the station
- The Command and Monitoring Unit (CMU) and, for the Jules Verne flight only, the redundant KURS transponder for independent range and range rate measurements during the rendezvous phase

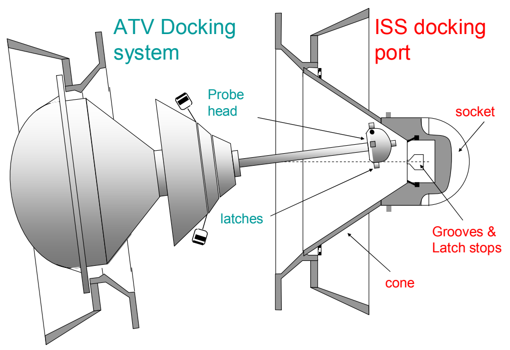
The ICC pressurized module is designed to support Intra Vehicular Activities (IVA).

On the external side of the EPM front cone, the following avionics and propulsion items are mounted:

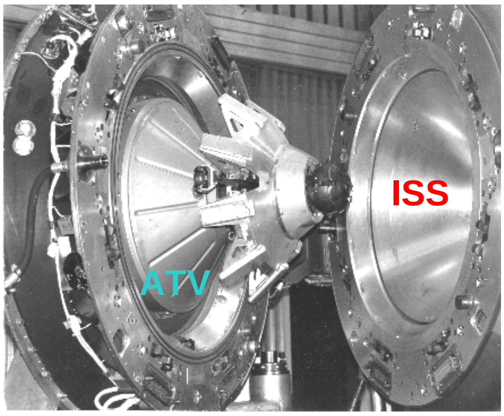


- 2 TeleGonioMeters (TGM) and 2 ViDeoMeters (VDM)
- 2 Star TRackers (STR)
- 2 Visual Video Targets (VVT) with their illumination devices for video monitoring of the ATV final approach by ISS crew
- 8 Front Attitude Control System Thrusters (FACS) arranged in 4 clusters and their associated latch valves.
- KURS antenna
- A proximity link antenna is mounted on a deployable boom attached to the EPM shell.

The **Docking System** is installed on its dedicated adapter cone. This is a “probe and drogue” type system, long-used by the Russian vehicles and modules, which ATV inherited to ensure its compatibility with the ISS Service Module docking port.

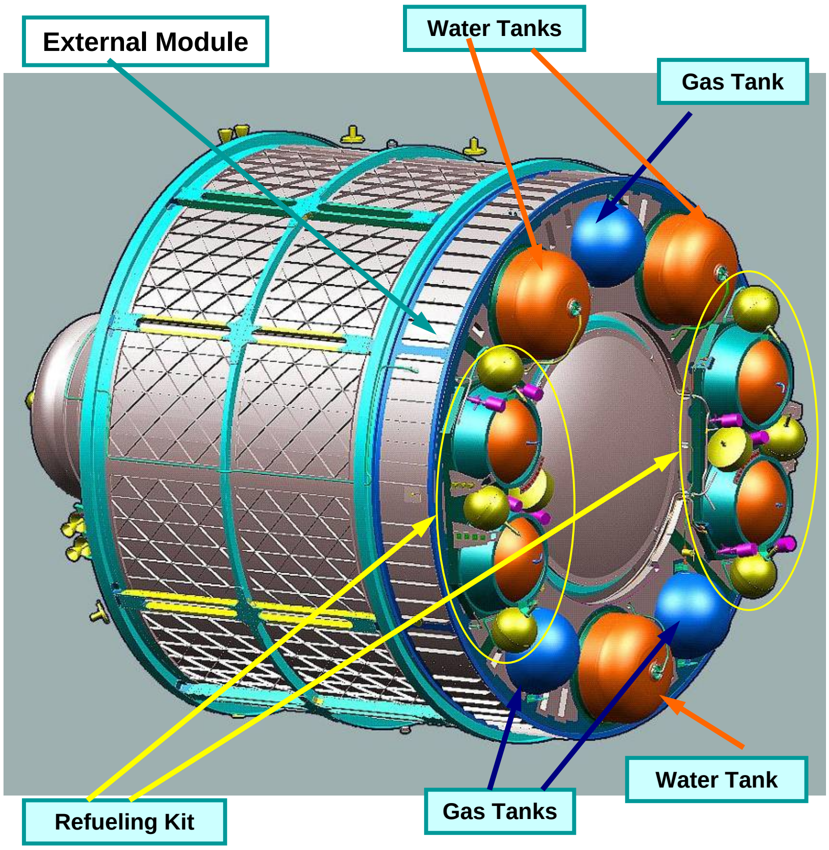


ATV to ISS docking using “probe and drogue” concept



Equipped External Bay (EEB) is a non-pressurized compartment accommodating the refuelling system with up to 860 kg of UDMH / N2O4 as well as 940 kg of fluid cargoes in water (840 kg) and gas (100 kg) tanks. It also provides for a mechanical interface with the Spacecraft. The EEB includes:

- an external module structure,
- 2 refuelling kits each consisting of 1 oxidizer tank, 1 fuel tank and 3 high pressure tanks,
- 3 water tanks,
- 3 gas tanks.



The Water Delivery System allows the unloading of up to 840 Kg of drinkable water (from the ATV tanks to the ISS) and the reloading of up to 840 Kg of ISS liquid waste (from the ISS tanks to the ATV tanks) by the ISS crew in a pressurized environment.

The 3 tanks of the water delivery system allow the loading of ISS liquid waste and delivery of drinkable water to be performed in parallel.

All water transfer operations are manually commanded by the crew inside the ATV pressurized module and monitored by ATV/CC and ISS (laptop).

The Gas Delivery System allows the release of up to 100 Kg of gas (2 gases maximum per flight: air, oxygen or nitrogen). The 3 tanks and the piping of the gas delivery system impose the ratio between the two gases to be as follows:

- mass of the first gas < 100 Kg x 2/3
- mass of the second gas < 100 Kg x 1/3

The gas delivery is delivered upon ISS crew manual control inside the ATV pressurized module.

4-2. Spacecraft

The **Spacecraft** consists principally of two bays for Avionics and Propulsion.

The **Equipped Avionics Bay** (EAB) is a non-pressurized compartment that accommodates most of the ATV avionics, such as:

- 4 rechargeable batteries NiCd as well as 4 Power Conditioning and Distribution Units (PCDU)
- Fault Tolerant Computer composed of 3 Data Processing Units (DPUs)
- Guidance, Navigation and Control sensors, e.g. gyrometer assembly and 3 accelerometers
- 2 computers dedicated to Safety Monitoring (MSU)
- Communications equipment
- 4 Thermal Control Units (TCU)
- 1 Command and Monitoring Unit (CMU)

Each equipment tray is thermally controlled by means of an Active Fluidic Cooling Unit (AFCU) including Variable Conductance Heat Pipes (VCHP) and interfaces with radiator assembly.

The Radio Frequency communication antennas (TDRSS and Proximity link) and the GPS receivers are externally mounted on the EAB structure.

Some avionics units, e.g. Russian Systems avionics (RECS), Star Trackers, TeleGonioMeters, ViDeoMeters are located outside the EAB (located on ICC pressurized module).

The ATV capabilities and resources are implemented in the corresponding hardware chains and their relevant software that compose the overall avionics setup allowing ATV autonomous functioning, ATV interfaces with the external resources, the vehicle controllability and operability by the ATV-CC and the ISS, implementation of docking and attached operations as well as the vehicle survival mode.

The ATV avionics concept is built around the following major design features:

- The hardware chains are organized in 4 lanes, each having its own power distribution bus and a relevant 1553 data bus,

- The 4 avionics lanes are totally electrically independent with the redundant units allocated to different lanes to allow for the ATV survival in case of complete loss of any lane,

- Overall avionics architecture is organized in a centralized way around the Fault Tolerant Computer (FTC). The **FTC** (a carryover from the DMS-R project) is composed of 3 independent Data Processing Units (DPU) that exchange and vote their data. The FTC hosts the main system operating software (FAS – Flight Application Software) in which the ATV main functions such as Mission and Vehicle Management, Flight Control and Flight Control Monitoring are programmed. Each DPU is capable of communicating with all 4 ATV MIL 1553 B internal data buses.

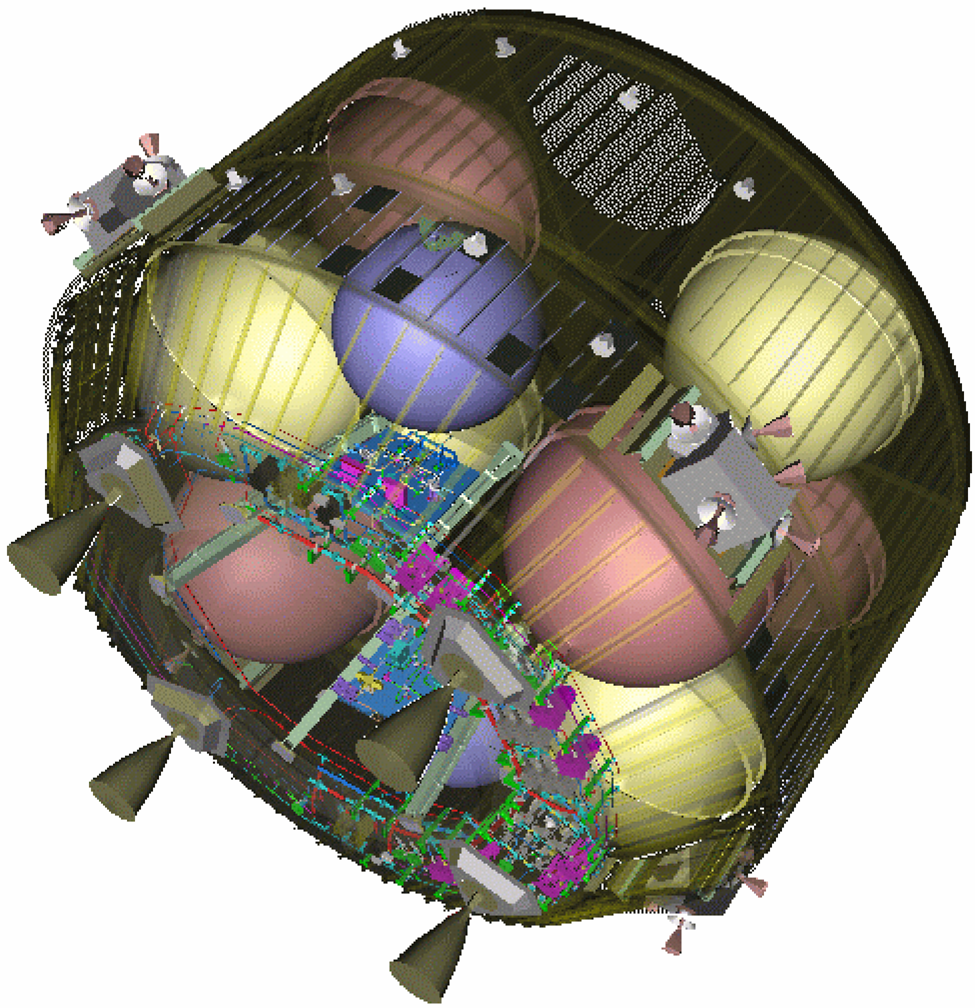
- An independent Proximity Flight Safety (PFS) chain ensures in the last resort the safety of ATV operations in the ISS proximity. In case of contingency, this completely

segregated chain provides the capability for a Collision Avoidance Manoeuvre (CAM). The Proximity Flight Safety chain is based on dedicated computers: **MSU** (Monitoring and Safety Unit) that house associated software. It includes independent CAM actuators as well as dedicated power source (non-rechargeable batteries) that allow bypassing of the nominal chains in the event of a safety critical failure

- The **Communications** equipment is based on two segregated Radio Frequency (RF) chains, one redundant for TDRSS and one redundant for proximity link

- The ATV **Power System** is composed of 4 identical completely independent power chains (4 Power Conditioning and Distribution Unit, PCDU, distribute power from the Solar array and Batteries) and specific equipment for safety and docking systems.

The **Equipped Propulsion Bay** is a non-pressurized compartment structurally composed of a Thruster and a Tankage module. The EPB mainly accommodates the Propulsion and Re-boost Subsystem.



The **Propulsion and Re-boost Subsystem (PRSS)** accommodated mainly in the EPB is a MON /MMH bi-propellant system and can be broken down into:

- The pressurisation subsystem: which pressurises the propellant tanks with helium stored in 2 high pressure bottles,

- The propellant storage and distribution: 8 tanks (4 MON and 4 MMH) and the distribution piping and latch valves down to the engines.

The propellants are stored in 8 identical surface tension titanium propellant tanks (4 for MON and 4 for MMH) with overall maximum capacity of nearly 7 tons of propellant for both ATV propulsion and ISS re-boost needs. The propellants used for ATV propulsion and for the ISS re-boost are not allocated to specific tanks. A proper propellant consumption management throughout the mission may allow to save/re-distribute propellant between the propulsive phase and the station re-boost activities.

- The Service Valves Assembly used on ground to test the sub-system and to fill all tanks with propellants and helium,

- The PDE (Propulsion Drive Electronics): which receive power from the PCDU and commands from the FTC, and transmit status of the Propulsion S/S to the FTC. The PDE also receives CAM commands and power from the MSU,

- The engines (main and attitude control): which provide thrusts

The ATV orbit transfer (phasing, de-orbit), re-boost and debris avoidance manoeuvre of the ISS are performed by the **Main Engines** also named Orbit Control System (OCS). 2 of the 4 main engines are used for orbit manoeuvres in Free Flight with two others serving for redundancy, whereas all 4 main engines can be used for ISS re-boost. Their thrust level is 490 N each, the specific impulse exceeds 310 s at reference point.
The ATV attitude control and all the manoeuvres for rendezvous with the station are performed by means of the **Attitude Control System** (ACS) that includes 28 ACS thrusters. The ACS also contributes to ISS attitude control in the attached phase. Twenty ACS thrusters are positioned in four clusters at the bottom of the ATV EPB and 8 remaining in four clusters are located on the ICC front cone (Front cone ACS or FACS). The engines are of about 220 N each, their specific impulse is 285 s.

In addition, to perform the Collision Avoidance Manoeuvre (CAM) commands, related to the Proximity Flight Safety Function, each PDE channel is associated with an independent board, provided with hardware logic and independently commanded by the Safety Chain in order to inhibit all nominal thrusters' operations, to command 4 predefined CAM thrusters (one of the 2 breaking thrusters of each ACS cluster is reserved for this Safety Chain) and to open/close isolation latch valves, once the Collision Avoidance Manoeuvre (CAM) command is issued.

In addition to the propulsion and re-boost subsystem, the EPB accommodates two non-rechargeable (LiMnO2) batteries used for MSU and RECS as well as the Power and Control Unit (PCU).

Among other avionics items, one internally redundant Sun Sensor and one KURS antenna are also implemented on the EPB aft part.

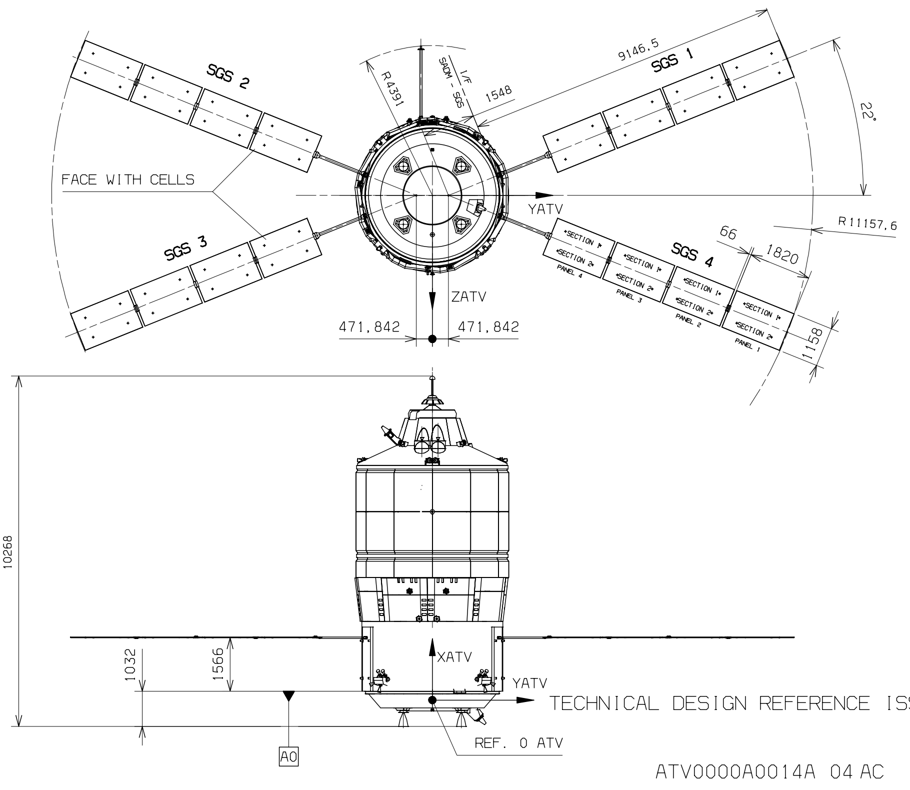
The EPB shell is protected by the Micrometeoroids and Debris Protection Subsystem (MDPS).

4-3. Power Sources

The ATV power sources are composed of:

- 4 Rechargeable batteries, NiCd technology of 40 Ah capacity, to provide power during the eclipse and during the transient phases (rendezvous phases, launch, attached phase)
- Solar generation subsystem to provide power during the day to users and to recharge the batteries
- 4 Non rechargeable batteries composed of 33 cells LIMnO2 technology of 86 Ah capacity, to provide power to specific equipment (safety and the docking system)

Externally, the EPB accommodates 4 deployable, sun tracking solar array wings, featuring 4 panels each.



During launch, the wings are stowed against the side walls of the Spacecraft. Four Hold-Down & Release Systems (HDRS) insure stowage of the wings to the spacecraft. The deployment of the solar array is initiated by cutting the restraint cables at the hold-down points with dedicated Thermal Knives.

Each panel consists of an aluminium core and Carbon Fibre Reinforced Plastic (CFRP) rigid sandwich face sheets, covered by Si high ETA2 solar cells.

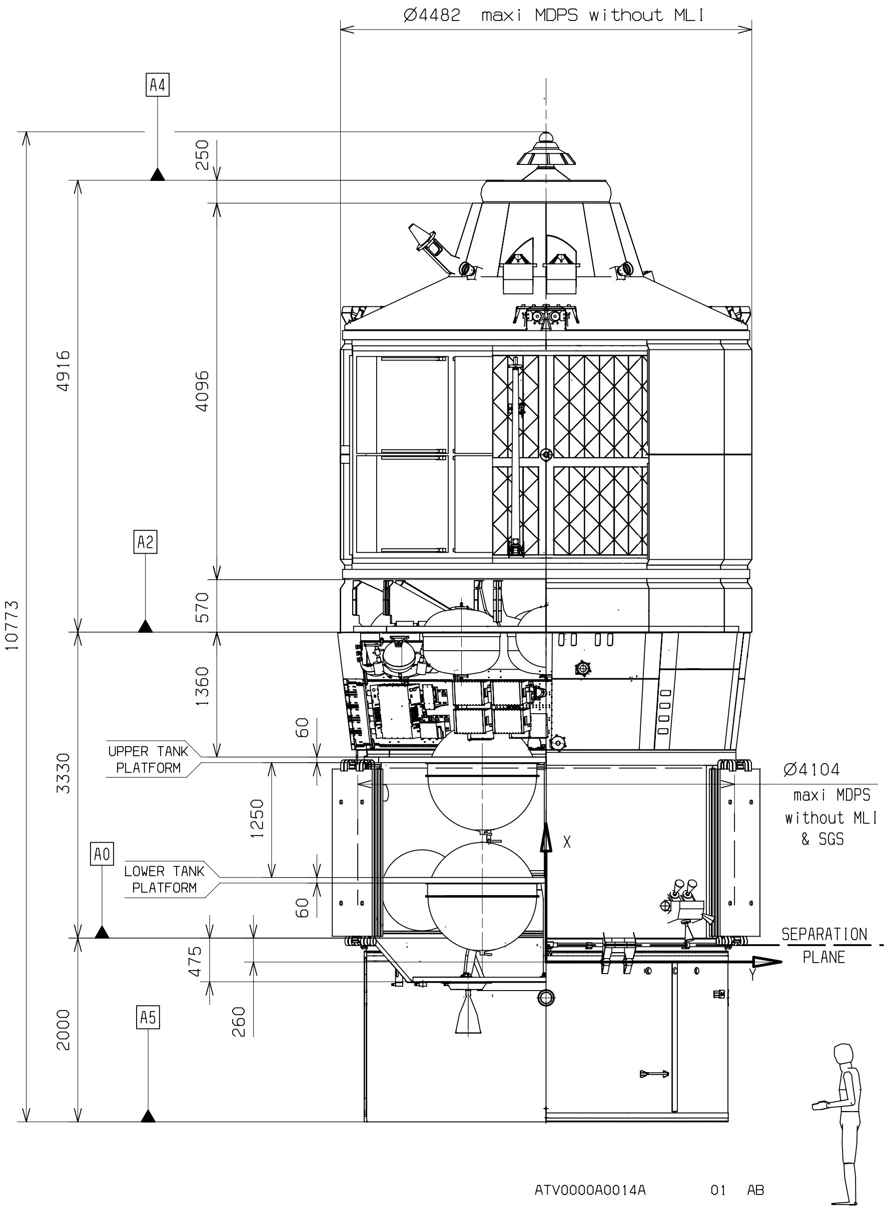
One solar wing provides power of 1135 W (end of life, solar pointing mode). During the mission the solar arrays are in rotating mode and provide variable power from 250 W to 1135W (for each wing) depending on ATV attitude (Sun angle incidence and shadow)

During the attached phase, the ISS is able to provide power to ATV through two ISS panels with a maximum capability of 50A each under a nominal voltage of 28.5 V. ATV uses from 400 W during “Dormant” mode up to a maximum of 900W during active operations.

Power is distributed to up to 80 “users”, for a total ATV power load from 1200 to 2300 W depending on the mission phase.

4-4. Main ATV 'Jules Verne' Characteristics

Dimensions	
Total Size:	- 10,77 m (With Separation and Distancing Module) - 9,79 m (without SDM)
Total wingspan:	22,28 m
External diameter:	4,48 m
Pressurized volume	
Total:	46,5 m3
Cargo volume accommodation:	23 m3
Useful volume in the rack:	16 m3
Mass	
Mass at lift off:	**19 356 Kg**
« Jules Verne » dry mass :	9784 Kg (345kg on A5 after separation)
Propellant (MMH, MON) :	5858 Kg
MMH (2177 Kg), MON (3675 Kg)	
Planned for the ISS Re-boost:	2300 Kg
ATV Mission:	3558 Kg
Cargo:	2297 Kg
Water:	270 Kg
Gas (Oxygen):	21 Kg
Propellant for ISS « Refuelling »:	856 Kg
Dry Cargo:	1150 Kg
Bags and structures for Dry Cargo:	1417 Kg
Total « Jules Verne » Cargo delivered	**4 597 Kg** (Propellant for ISS Re-boost and Refuelling, water, gas, dry cargo)


Ø4482 maxi MDPS without MLI
A4
250
4916
4096
A2
570
10773
1360
60
UPPER TANK PLATFORM
3330
1250
A0
LOWER TANK PLATFORM
60
475
2000
260
A5
Ø4104
maxi MDPS without MLI & SGS
X
SEPARATION PLANE
Y
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5. ATV Development Phases

5.1. Planning

The main milestones of the development phase have been:

Preliminary Design Review (PDR) board	14/12/2000
Critical Design Review (CDR) board	04/06/2003
Qualification Review part 1 (QR1) board	28/05/2005
Qualification Review part 2 (QR2)	
▪ Advanced QR2 - Flight Control Pre-board	29/11/2006
▪ Final QR2 board	05/10/2007
Jules Verne Pre-shipment Review board	04/07/2007
Jules Verne Acceptance Review board	08/01/2008

5.2. Qualification logic

The qualification process of ATV Flight Segment and interfaces verification is based on the following main models and platforms:

- **at subsystem level:**

- the Avionics Electrical Test Model (ETM) at Astrium Toulouse premises,
- the Propulsion Qualification Model (PQM) at Astrium Space Transportation Lampoldshausen premises,
- Russian System models and associated facilities at RSC ENERGIA Moscow premises,
- different Software Validation Facilities (SVF) at Astrium Space Transportation Les Mureaux premises.

- **at Flight Segment level:**

- the Structural Thermal Model (STM) at ESTEC premises used for dynamic and thermal tests,
- the ETM (Avionics ETM with complements) and Flight and Safety System Software at Astrium Space Transportation Les Mureaux premises: the ETM with associated ground test facilities constitute the Functional Simulation Facility (FSF),
- the Proto Flight Model (PFM) at Astrium Space Transportation Bremen, then ESTEC, and finally the Guiana Space Center (CSG) .

The ATV functional qualification has been based on a set of functional tests performed on several platforms:

- Stand alone functional tests performed on a real time platform located at Les Mureaux (Functional Simulation Facility: FSF)
- Joint Validation Tests with ISS performed mainly on other ATV platforms located at Moscow (interfaced with Russian facilities) and at Val de Reuil (RDV validation wrt. VDM and TGM optical aspects)
- System Validation Tests with ATVCC performed on FSF and on Jules Verne

5.3. Structural Test Model

The STM campaign was successfully completed in September 2002.

The complete test sequence was as follows:

- the acoustic test,
- the modal survey and dynamic qualification tests,
- the SHOGUN test (verification of fairing jettisoning shock),
- the clamp band release test,
- the solar arrays deployment test,
- the thermal balance test.

All these activities were performed at ESTEC test center in Noordwijk, the Netherlands.

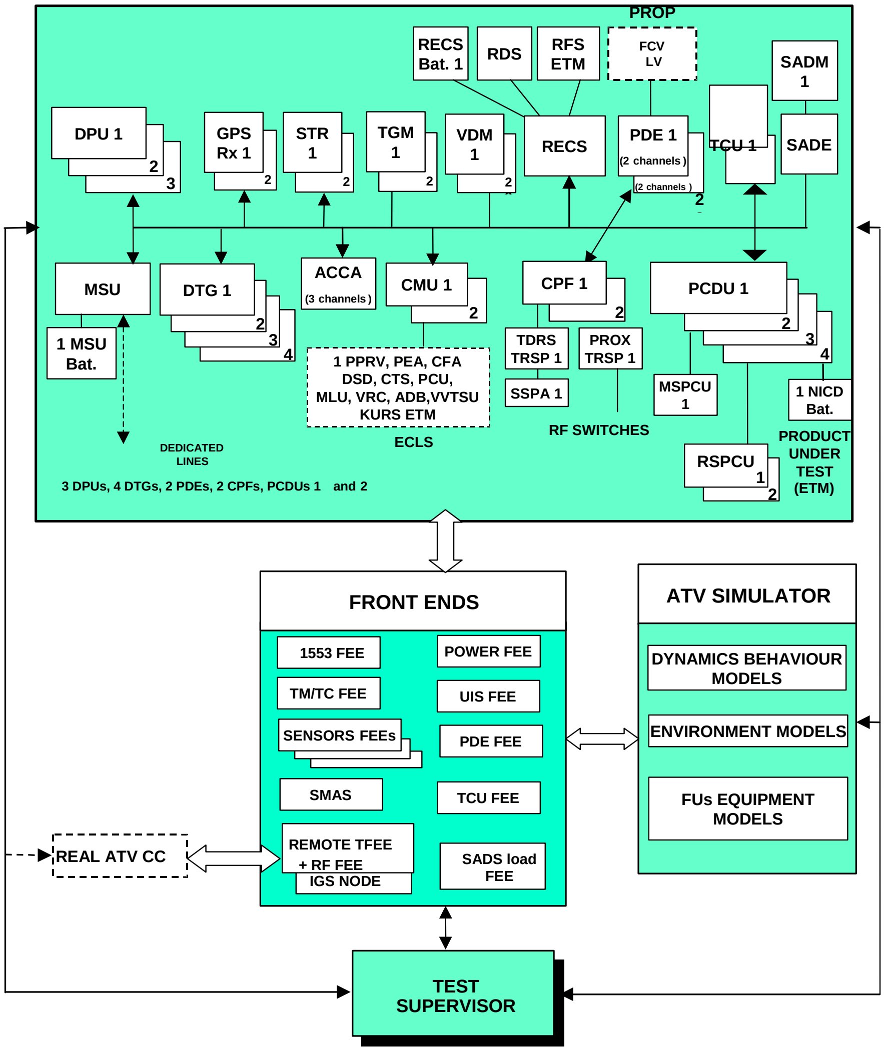
5.4. ETM and Functional Qualification Tests

The Functional Simulation Facility (in Les Mureaux), integrating the ATV Electrical Test Model, the Flight application Software and the System Data, has been the main platform used for the functional qualification. On it have been run more than a hundred of formal closed loop tests covering nominal and degraded scenarios for different mission phases (LEO, Transfer to Phasing, Rendezvous and Docking, Attached, Departure, Deorbitation).

FSF building is constituted of 2 rooms:

- The control room with the Test Supervisor and Operators to conduct the tests
- The clean room where real ATV equipment are located (most of avionics equipment are installed on the EAB mechanical mock up and Russian equipment are located on a dedicated structure) and most of GSE front ends.

FSF is composed of around 90 pieces of ATV equipment (engineering, qualification and flight models); all redundancies of avionic equipment are present (particularly for DPUs, PCDUs, CPFs, CMUs, MSU, sensors, PDEs), ground support equipment including a Test Supervisor and a set of front ends (60 racks). Missing equipment and flight dynamics are modeled in ATV simulator.



FSF integration started end of 2002 and, first, electrical qualification tests were achieved on this platform till end of 2004 (35 tests). Then, validation tests of FSF platform to demonstrate its representativity wrt. subsystem tests or Jules Verne tests were performed in 2005 and early 2006. The Qualification Team made all dry run and formal functional tests from beginning of 2006 till September 2007.

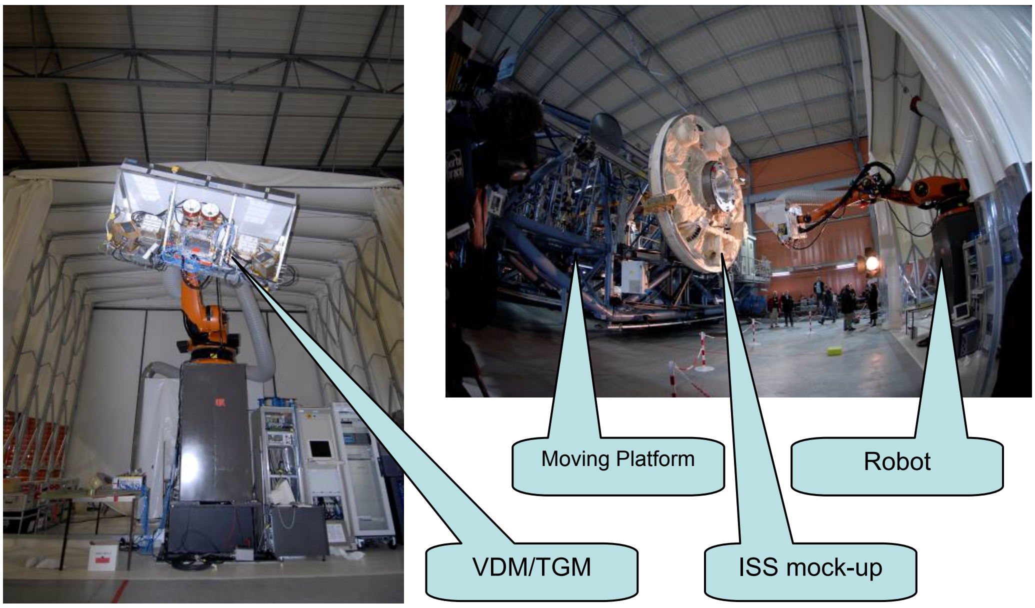
Finally, some non regression tests, long duration tests and software patch tests with final FAS version were performed at the end of 2007 and early 2008 to prepare the Jules Verne flight.

5.5. Main External Interfaces Tests

ISS and ATV interfaces - Bilateral Interface Validation Plan Tests (BIVP).

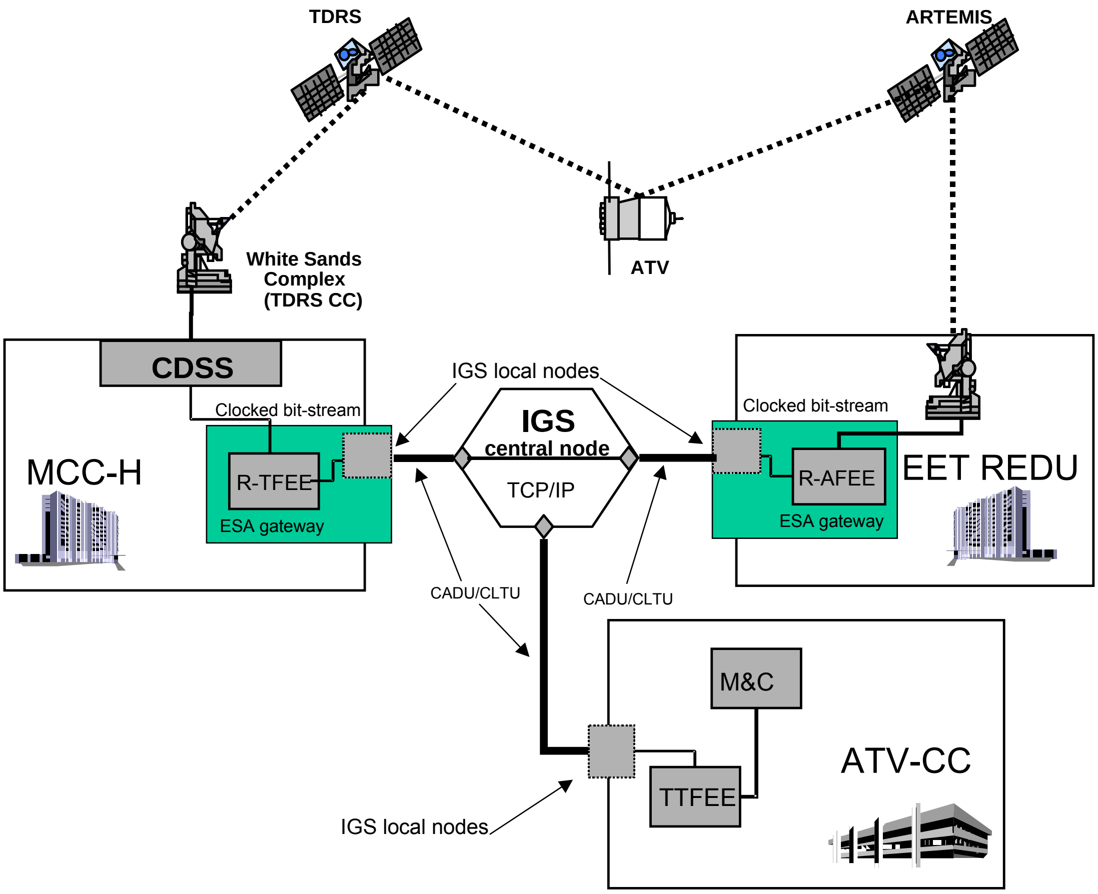
BIVP tests have been performed -- mainly in Moscow -- with flight equipment items and test facilities (including a simulator able to simulate the ATV behaviour during flight), connected to the RSC-E facility which simulates the ISS (GDC) or an engineering model of the ISS Russian segment (KIS). Tests have been run to validate the rendezvous and docking scenario as well as sequences linked to the “Attached phase” (Refuelling, Reboost …).

Other BIVP tests have been run in a full scale rehearsal of a rendezvous, from 250m (S3) to docking, with the real equipment items, in particular the ATV Flight Application Software (GNC closed loop), and the real optical interface between ATV (real VideoMeters and Telegoniometers sensors fixed on a Robot) and ISS (mock-up simulating the docking port fixed on a moving platform). The relative movement of the chariot and the robot, simulating the relative movement of the ATV and the ISS, is managed by a simulator. This dedicated Interface Validation test (EPOS) has been performed in the “Bassin d’Essai des Carènes” (at Val de Reuil near Paris). The size of this facility (545m) enabled performance of this full scale rehearsal of a Rendezvous.



System Validation Tests (SVT): Joint tests with ATV-CC.

Interface tests between the ATV-CC and the ATV have been run in several steps, from a simple compatibility test to check the Radio Frequency links between ATV-CC and Jules Verne (at ESTEC and Kourou) through the satellites used in flight, up to simulated mission rehearsals where the ATV "Jules Verne" (at ESTEC and Kourou) in closed loop simulation was controlled from the ATV-CC.



5.6. 'Jules Verne' Assembly, Integration and Test

The Proto Flight Model Jules Verne also serves as a qualification model. It should be mentioned that for planning purposes the ICC Equipped Pressurized Module (EPM) used for the ATV Jules Verne is the second EPM manufactured, and not the PFM. This latter has been used for qualification tests and will be refurbished and used later on for further ATVs. This paragraph describes the overall flow of activities from subassemblies' integration up to the completion of the Jules Verne tests before shipment to the launch site.

At Subassembly level the flow begins with the integration of the Equipped Avionics Bay (EAB), the integration of the Equipped Propulsion Bay (EPB) and the integration of the Integrated Cargo Carrier (ICC). These integration activities took place on different sites in Europe: Toulouse for the EAB, Bremen for the EPB and Turin for the ICC.

After completion of a Thermal Vacuum Test, the EAB was transferred to EADS-ST Bremen for integration with the EPB to form the Spacecraft (S/C). The ICC was transferred to Bremen as well. Then for the first time, the ICC and the S/C were electrically connected and the first functional tests on the Jules Verne conducted, using the EGSE and specifically developed ground procedures.

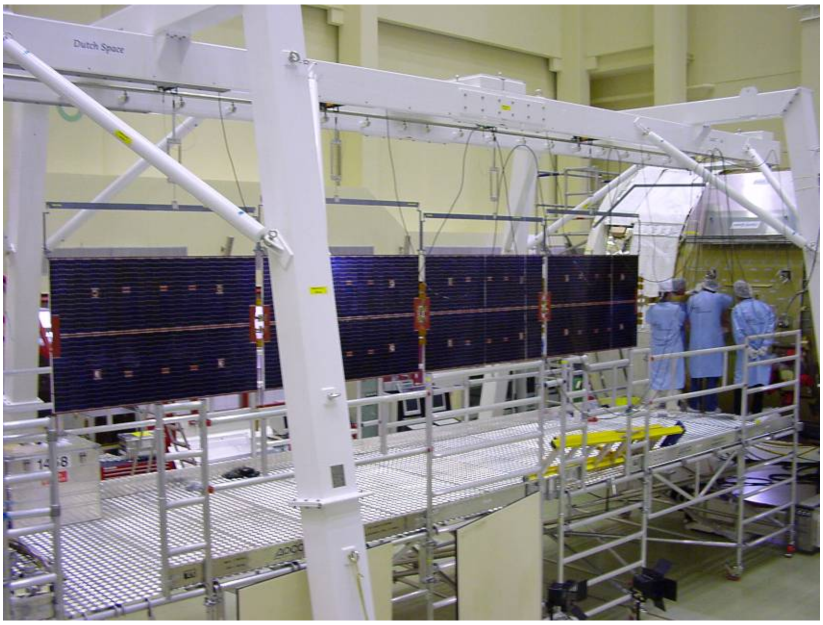
The ICC and the S/C were transferred to ESTEC in July 2004. The transfer was by Beluga aircraft from Bremen to Amsterdam airport, and then by barge and road to the ESTEC test centre.

At ESTEC, complementary integration activities such as the integration of the Russian Electronics Control System (RECS) were performed. Then, for the first time, the S/C and ICC Jules Verne were mechanically and electrically mated. The EMC tests in the ESTEC Maxwell chamber were run. These tests checked that the ATV electrical chains are not affected by external EMC perturbations. The next test was a qualification electrical test where all electrical chains were activated to simulate worst electrical flight configurations. The electrical interfaces with the ISS have been tested too.

ATV Jules Verne in the EMC chamber (ESTEC)

Next, some complementary integration activities were performed. The Late Cargo Access rehearsal was conducted to demonstrate the capability to perform last-minute loading of dry cargo inside the ICC before flight. Some inspections of the ICC by crew members were performed to check the compliance of the design with "human factors rules" imposed on any element of the ISS.

This phase ended with the integration of the solar wings.



Integration of the Solar Arrays (ESTEC)

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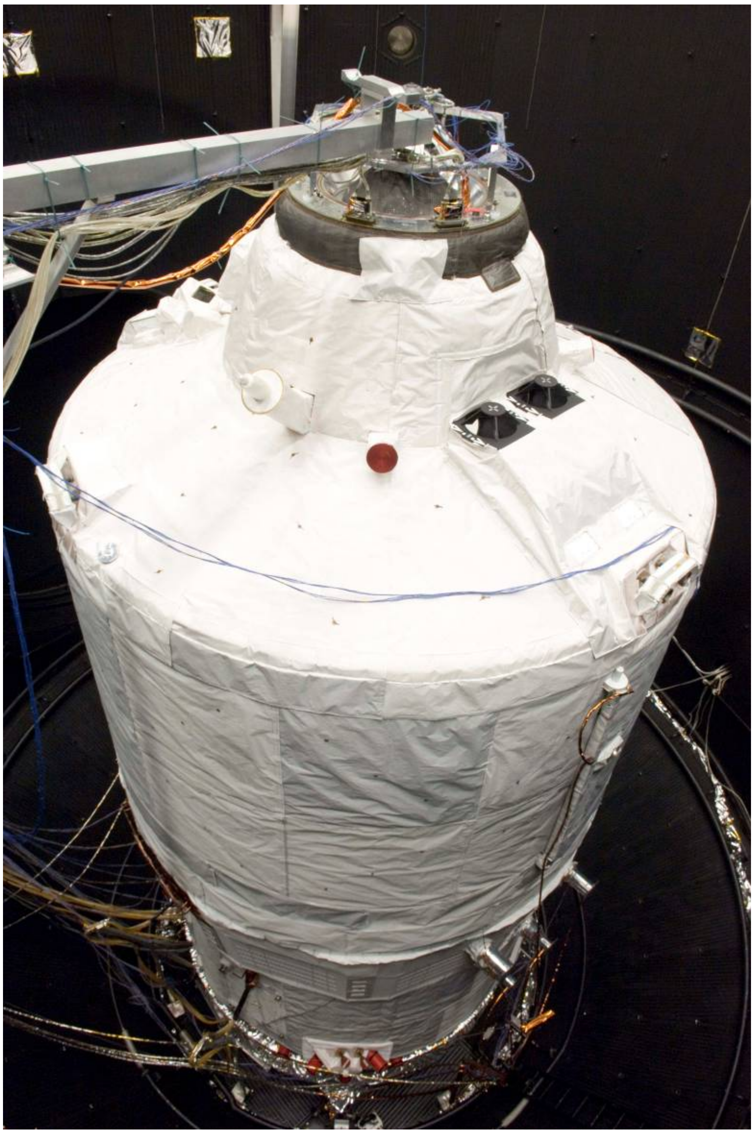
The S/C, ICC and the SDM were then mated and the ATV transferred to the acoustic chamber (Large ESTEC Acoustic Facility, LEAF), where it underwent an acoustic environment representing the noise generated during Ariane 5 take off. This acoustic test was completed in June 2006.

ATV "Jules Verne" in the Large ESTEC Acoustic Facility (LEAF)

After this acoustic test, several checks were performed to verify that no degradation due to acoustic loads had occurred: functional checks, propulsion leak tests, Refuelling system integrity checks, and a deployment test (July 2006) of all four solar arrays, followed by the solar arrays dismounting

The S/C and ICC were then prepared for the **Thermal Vacuum Test** (TVT). The S/C and ICC were moved into the vacuum chamber (**Large Space Simulator,** LSS) where they were mated again. Functional tests were performed, as well as a complete dress rehearsal of the tests planned to be performed during the TVT. Then the chamber was sealed and a vacuum maintained for 3 weeks during which the ATV was activated under hot and cold conditions, simulating different phases of the mission. This test was completed in December 2006.



ATV in the Large Space Simulator (LSS in ESTEC)

After the thermal test, some functional tests were conducted in a configuration where the ATV is connected to a simulator and commands are sent from the ATV Control Centre. These are the SVT (System Validation Test) Closed Loop Test, where parts of the ATV mission are simulated in the same way as the qualification tests that have been run on the FSF.

After these tests, the Jules Verne ATV entered its final preparation phase where the last functional tests, inspections, and shipment preparatory activities were performed.

After successful completion of that step, the Jules Verne was ready for transfer to the Launch Site. The go ahead was formally given by the Pre Shipment Review.

The two weeks shipment from ESTEC to Rotterdam harbour and then to Kourou harbour began on July 13th 2007.

6. The 'Jules Verne' Launch Campaign

6.1. Transport

After completion of the activities at ESTEC, all ATV components, their accompanying GSE and some of the fluids necessary for the launch campaign (including the propellants) were transported by boat from ESTEC to Kourou, French Guiana. More than 70 containers representing about 500 metric tons of hardware were transported.

Arrival of the Toucan at Kourou harbour

In the harbour of Kourou, all the items were off-loaded from the ship and transported on trucks to the launch site.

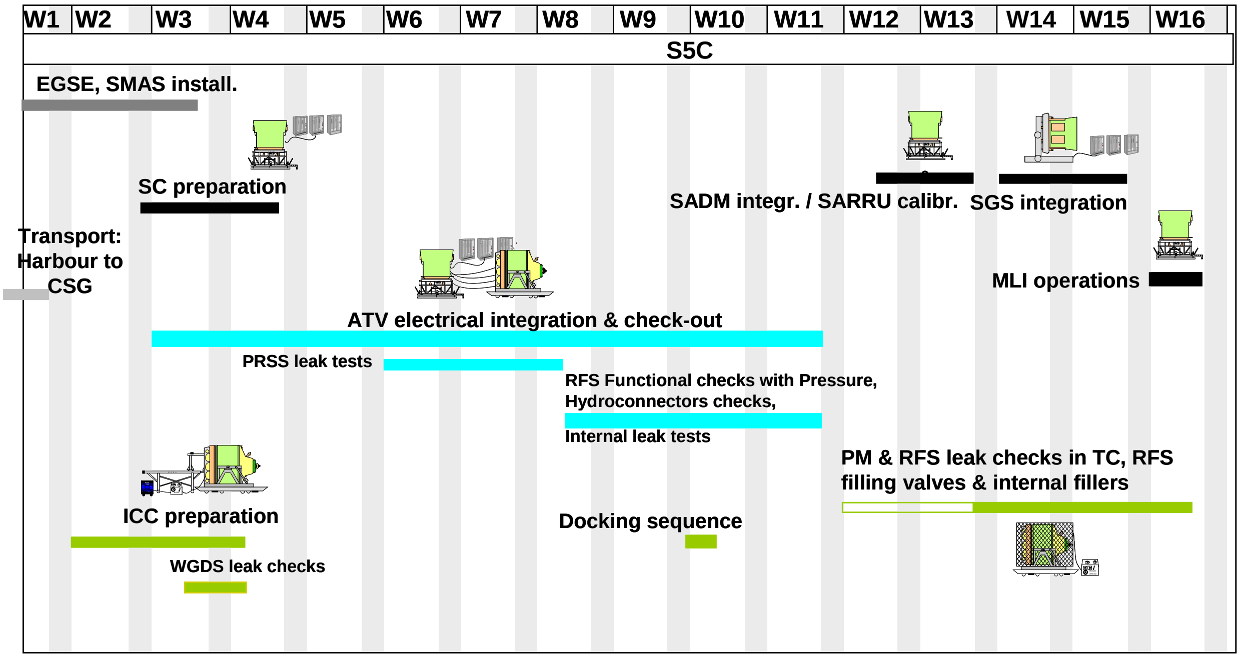
Transfer of the ICC to the Guiana Space Centre

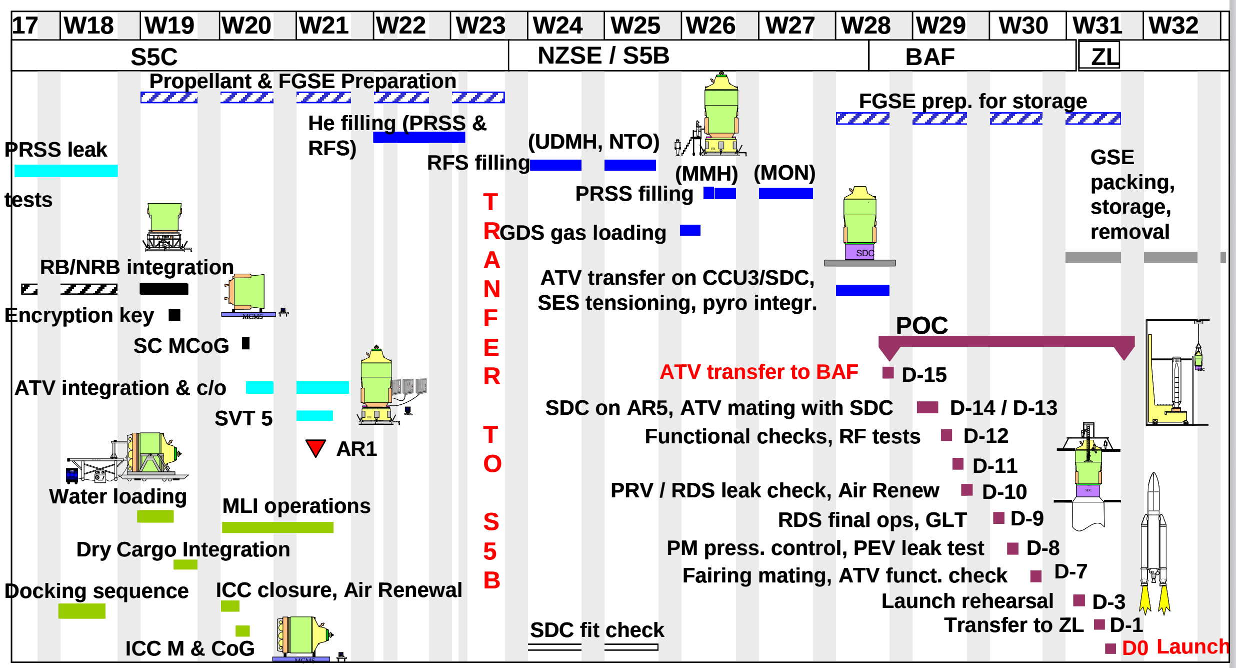
Some other items like the Dry Cargo have been transported by commercial airlines to Cayenne in French Guiana and then by road from Cayenne to Kourou.

After the launch of ATV by Ariane 5, the transport containers and some GSE will have to be returned to Europe. The remaining GSE will be stored in a dedicated building at the launch site, under controlled environmental conditions for reuse during subsequent ATV launch campaigns.

6.2. Ground Processing

The Ground Processing starts at the launch site after the transportation of ATV from Europe to Kourou. It ends with the launch of ATV by Ariane 5.





The preparation of ATV for launch, including its filling with propellants, is performed in the EPCU3 (S5) facility. The integration of the ATV on the launch vehicle is performed in the BAF ("Bâtiment d'Assemblage Final"). The launch is performed in ZL ("Zone de Lancement).

At their arrival in the EPCU3 all the elements were unpacked and inspected.

From left to right: the ICC, the SDM (being unpacked) and the S/C

Then, for several weeks, the ATV Spacecraft and the ICC were processed and checked-out, in the Integration Hall of the S5C building.

These activities started with the leak checks of the water and gas tanks of the ICC.

Then some functional tests verified the good health of all equipment.

Functional tests and leak checks of the propulsion subsystem followed.

Next the Refuelling System was functionally tested. A docking rehearsal was performed to check the Russian Docking System.

Docking rehearsal

The spacecraft was then configured for the integration of the Solar Array Drive Mechanisms and Solar Arrays. The spacecraft was positioned horizontally and the four Solar Arrays integrated and tested sequentially.

Solar arrays integration

The spacecraft was then returned to a vertical position in order to allow the integration of the rechargeable and non rechargeable batteries, following which the Spacecraft was ready for final assembly with the Cargo Carrier.

In parallel, the tightness of the ICC pressurized module was checked, and the pressurized module configured for the dry cargoes integration. The tightness of the Refuelling System was checked as well and the refuelling system then configured for fuelling.

The water tanks of the ICC have been filled with 270 kg of water, configured according to Russian criteria. Several sampling and analyses have been conducted to check the water compatibility with ISS requirements.

The pressurized module was then cleaned and disinfected, and the integration of the dry cargoes performed. A total of 1150 kg of dry cargo (food, clothes, etc) packed in standard bags have been loaded in the pressurized module racks. After a last inspection, the pressurized module was closed.

Dry cargo integration

In this final configuration before mating with the launcher, the ICC and the S/C have been weighed and the determination made of their centre of gravity.

The final version of the Flight Application Software has been loaded, and the Spacecraft and ICC have been mechanically and electrically mated together in the S5C Integration Hall. This was followed by some electrical tests to check the correct connection, and by the welding of two propellant feed-lines to the Front Cone Attitude Control Thrusters (FACS) of the ICC and their leak test.

A System Validation Test (called SVT-5) was then performed, involving the ATV-CC in Toulouse and the ATV in Kourou, to check their ability to work together and to exchange telecommands and telemetry through the real TDRS and Artemis communication links.

It was then possible to proceed with the pressurization to 340 bar of the helium tanks of the Refuelling System. The Propulsion system was pressurized to 290 bars.

The ATV was then transferred into the S5B filling hall of the EPCU3 for the propellant filling operations.

Transfer to S5B

The propellants (860 kg) for the Refuelling system (UDMH and N2O4) were processed and the propellant loading was conducted.

Propellant loading operation (S5B)

The gas tanks of the ICC have been loaded with pure oxygen. A total of 19 kg of gaseous oxygen has been loaded.

The propellant tanks of the Propulsion Subsystem have been filled with MON and MMH propellants. A total of 5853 kg of propellant have been loaded. Pad pressurization of the loaded propellants has been performed as well.

In parallel, a fit check of the separation and distancing module (SDM) has been performed with the launcher.

Following the gas loading and propellant loading, the ATV was mechanically assembled with the SDM and flight plugs installed on the Pyrotechnic command lines. The ATV was placed in the CCU 3 air-conditioned container for transportation to the BAF.

The ATV was transferred from the filling hall (S5B) to the BAF (Final Assembly Building) on February, 14th 2008 in the so-called CCU 3(payload container), paving the way for the beginning of the Combined Operations Plan (POC) with the launcher.

The Separation and Distancing Cylinder (SDC) was then installed on February, 15th.

The ATV Jules Verne Vehicle itself was then lowered down on the SDC on February, 16th.

Once fully mated atop the launcher, the ATV Jules Verne was cleaned and latest operations performed (check of electrical and functional connections, countdown rehearsals, installation of latest thermal protections…).

The long fairing was finally installed on February, 25th, 2008, completing rather complex and long integration and test campaign.

7. 'Jules Verne' Mission

7.1. Launch Sequence Countdown

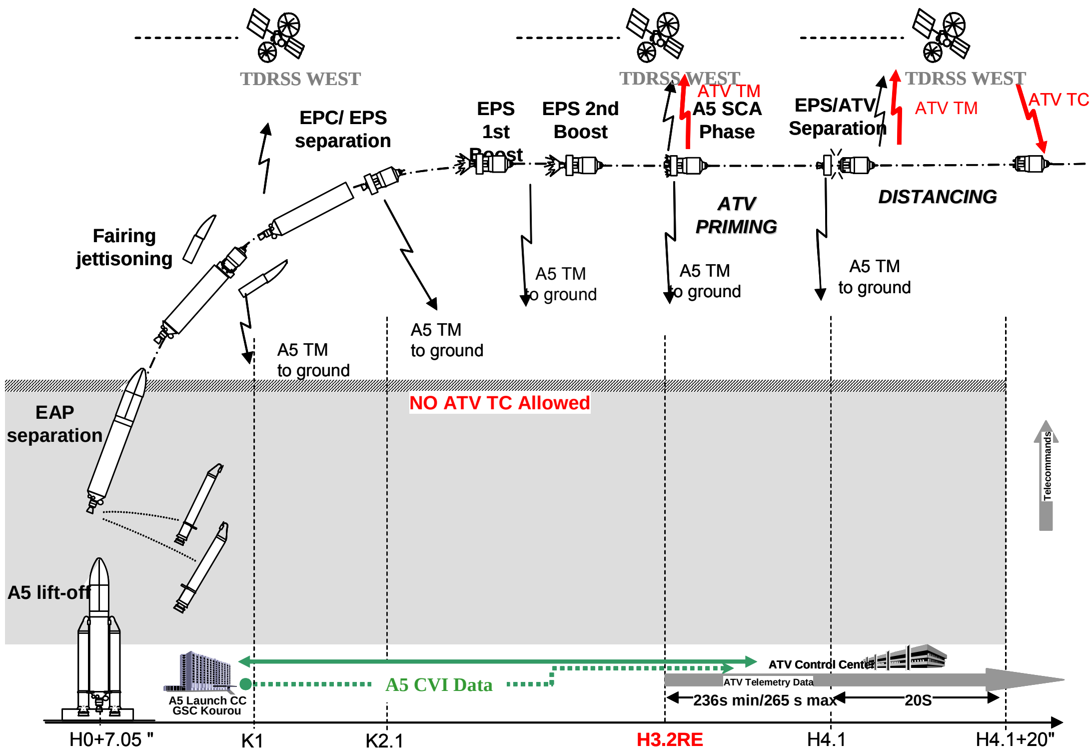
Main ATV operations during the sequence countdown from H0-9h to the lift-off:

- H0 - 10h: Start of the Countdown, GSE on, data transfer from ATVCC
- H0 - 8h: ATV on
- H0 - 7h30: ICC heating
- H0 - 7h15: Gyrometers on
- H0 - 6h: ICC heating verification - Go-No Go for A5 tank filling
- H0 - 2h: On Board Computers Time update
- H0 - 1h40: last data loading
- H0 - 1h: ICC temperature monitoring
- H0 - 15mn: End of the ICC heating
- H0 - 9mn: Switch to ATV on board batteries
- H0 - 8mn: Authorization to switch ATV to autonomous
- H0 - 7mn: ATV Ready for Launch. Start of synchronised sequence

7.2. 'Jules Verne' Flight Phases

LAUNCH BY ARIANE 5 AND EARLY IN ORBIT OPERATIONS

Ariane 5 launcher is the A5-ES version, including the EPS with a bi-boost capability. The launcher brings ATV into Low Earth (LEO) quasi circular orbit with 300 km orbital altitude and 51.6° inclination.



Following separation from Ariane 5 upper stage, about 70 minutes after lift-off, the ATV performs automatically a series of actions to set-up its on-orbit configuration, with necessary systems activated and operational. When it separates from the Ariane 5 upper stage, the vehicle stays in Earth pointing mode and the ATV's navigation-flight control and propulsion systems, already partially activated, are set in their free flight modes and configurations. ATV solar panels are deployed automatically, followed by the antenna for communications with the ISS. Then ATV goes to an attitude control mode that steers its attitude along its yaw axis to keep at the same time solar arrays exposed to the sun and the TDRS antenna pointed appropriately.

At this point, the ATV is in orbital configuration, with its solar panels tracking the sun to supply the electrical power needed by onboard equipment. The thermal control system keeps equipment at the right temperature, and the ground communications system operating via the Tracking & Data Relay Satellites (TDRS) and ARTEMIS is up and running.

PHASING WITH ISS

The ATV flight to the station (phasing) takes some 10 to 13 days and is aimed at bringing the ATV into the ISS vicinity, at the interface point named $S_{-1/2}$, from where the proximity communication link with the Space Station can be established. The ATV $S_{-1/2}$ point is typically located at 5 km below and about 39 km behind the ISS.

Throughout this phase, all ATV operations are controlled and monitored by the ATV Control Centre (ATV-CC) at CNES in Toulouse.

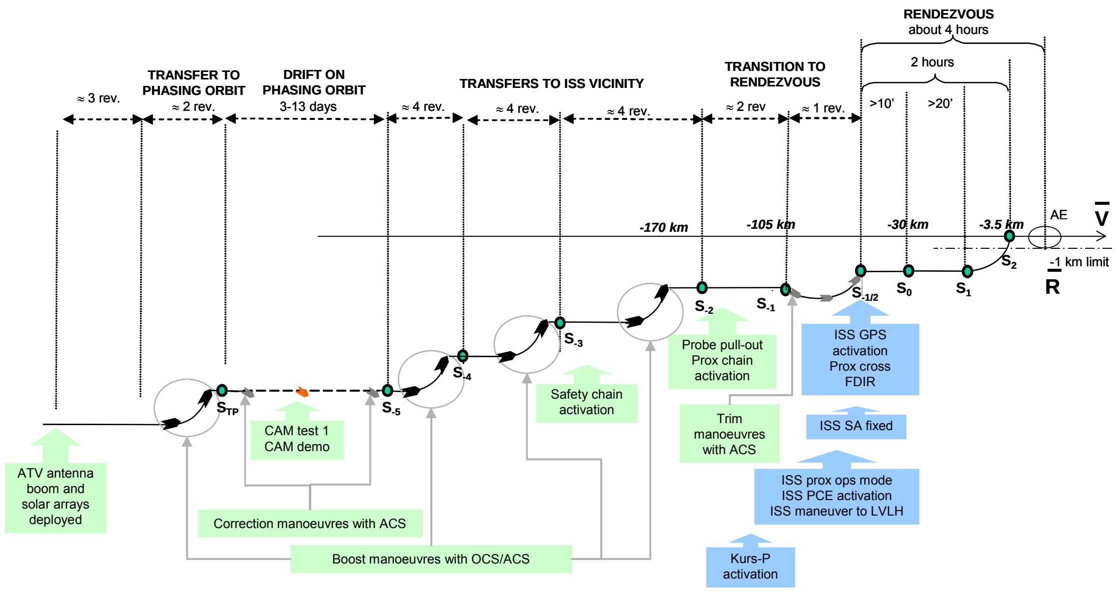
The phasing is broken down into four parts:

- transfer to the phasing orbit,
- drift on the phasing orbit,
- transfer to ISS vicinity,
- transition to rendezvous

The transfers are typically made of three main sets of boost manoeuvres; each transfer is composed of a set of boosts – Orbit Control System (OCS) boosts or/and Attitude Control System (ACS) boost - according to the transfer case.

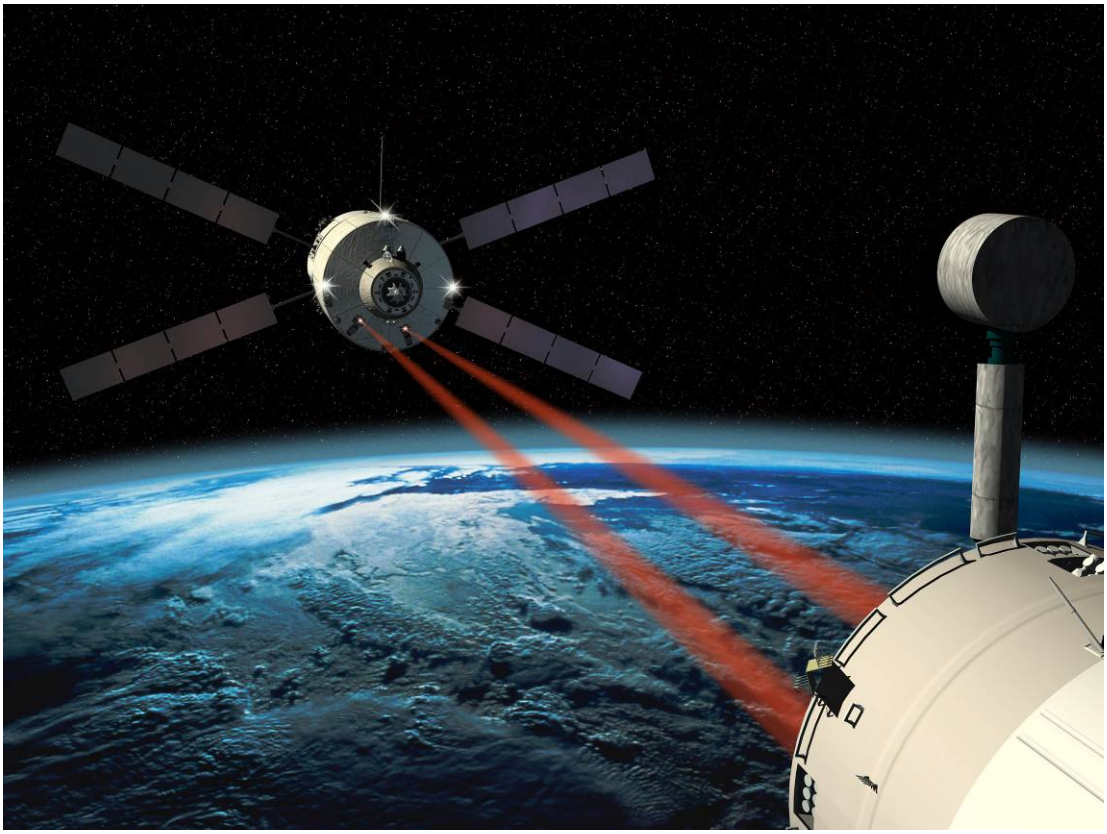
The drift consists in reducing the phasing angle and is made of a number of small correction boosts.

The transition to rendezvous consists of trim manoeuvres in order to compensate for dispersions encountered during the previous transfer. They take place at the end of phasing in order to achieve the accuracy requirements.

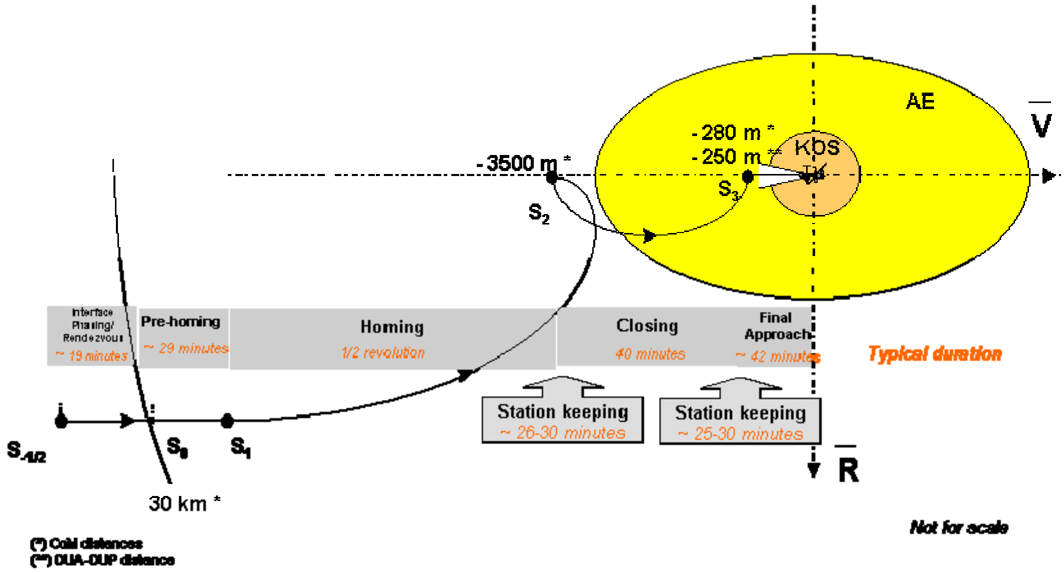


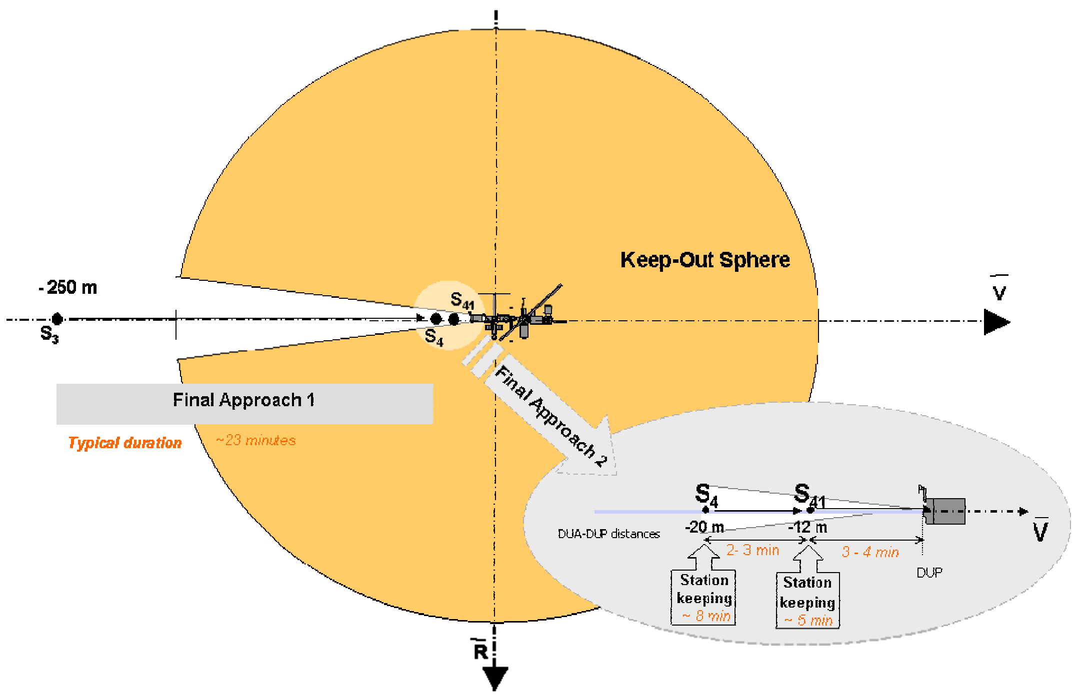
RENDEZVOUS AND DOCKING TO ISS

The ATV approach and docking are carried out in several steps under the combined responsibility of the ISS and ATV-CC. The highest priority throughout these operations is to insure crew and ISS safety. Thus, each step is subject to MCC authorization and is controlled by the ATV-CC.



The rendezvous starts with autonomously performed “homing” bringing the ATV into the ISS orbit at 3500 m from the station (point S_2) waiting for ground authorization before entering the Approach Ellipsoid. Further manoeuvres steer the ATV closer to the ISS and are subject to authorization from the ground at 250 m (S_3) and 20 m (S_4) and 12 m (S41) characteristic points.





In case of abnormal behaviour detected by its own means, the ATV on board software triggers an Escape Manoeuvre. If within very close range, the dedicated Proximity Flight Safety initiates a Collision Avoidance Manoeuvre (CAM) to put the ATV into a safe trajectory with respect to the ISS. In case of an emergency situation detected by the ISS crew or the ATV-CC, the CAM command is sent by either authority.

During the last part of the Rendezvous (the final approach is a forced translation from S3 to Docking), the crew also checks the ATV behaviour using the ISS Service Module video camera and video target patterns on the front cone of the ATV. Upon ISS authorization at 12m, the ATV-CC issues a final approach command to the ATV.

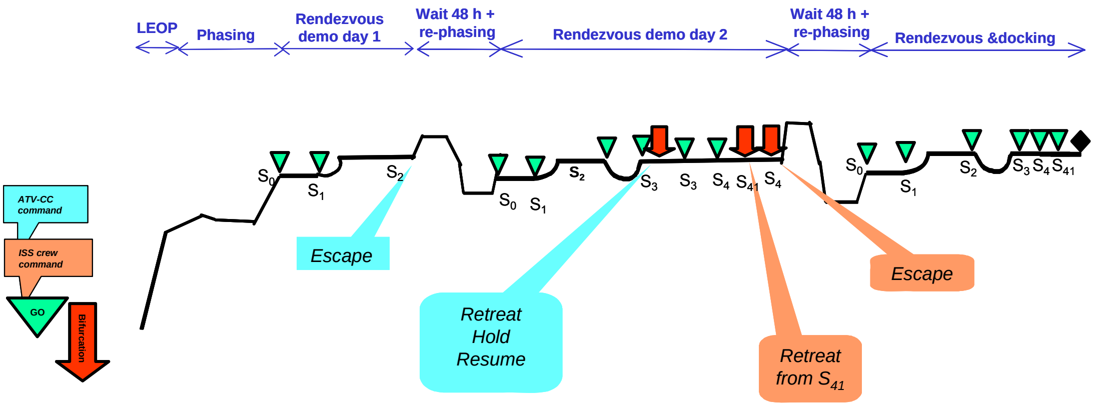
The ATV final approach to the station up to docking is supported by the ViDeoMeter (VDM), an optical sensor installed on the ATV front cone and used from 250 m distance to the station. To ensure its required performance, an assembly of dedicated laser retro reflectors (Rendezvous sensor target pattern) was mounted on the Service Module aft part in the frame of an EVA.

As soon as its docking probe touches the ISS, the ATV propulsion system provides the thrust needed to ensure its capture by the station's docking port. Subsequently, the automatic docking sequence is triggered on-board, the vehicle is mechanically attached to the station via a leak tight seal, and all the electrical, data and fluid connections are established.

After several checks, the crew opens the hatches and the ATV becomes an integral part of the International Space Station.

The Jules Verne Mission does include the demonstration of ATV spacecraft functionality prior to use in safety critical operations.

Indeed, an objective during phasing is to demonstrate the ATV capability to execute a Collision Avoidance Manoeuvre (see CAM Demo in the phasing timeline above). In the overall sequence of the ATV Jules Verne mission, two demonstration phases are planned prior to complete Rendezvous and docking.



- **Demonstration Day 1 and return**

During this phase of the mission (2 days duration), ATV will approach the ISS up to hold point S2, where an ESCAPE manoeuvre will be commanded by ATV-CC; after the ESCAPE, a series of orbital manoeuvres will return ATV to the interface point for the continuation of the mission.

- **Demonstration Day 2 and return**

During this phase of the mission (2 days duration), ATV will approach the ISS up to hold point S41, then back to S4 (RETREAT), where an ESCAPE will be commanded by Crew; after the ESCAPE, a series of orbital manoeuvres will bring ATV back to the interface point for the continuation of the mission.

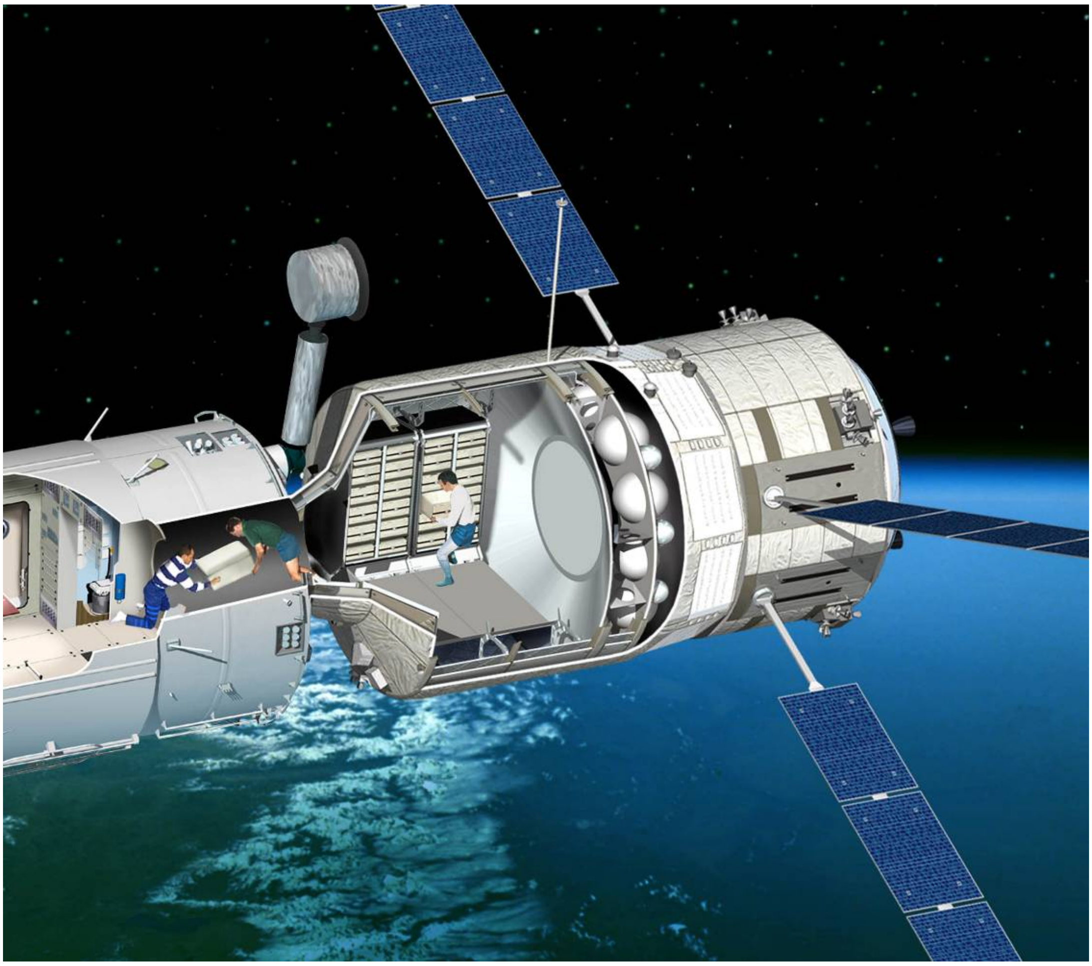
- **Rendezvous Day**

ATV will perform the Rendezvous and docking with the ISS. This phase lasts about 5 hours.

ATV OPERATIONS IN THE ATTACHED PHASE

Once docked to the Space Station, ATV begins to function according to an ISS operations timeline, performing the whole spectrum of attached operations in compliance with the ATV mission objectives.

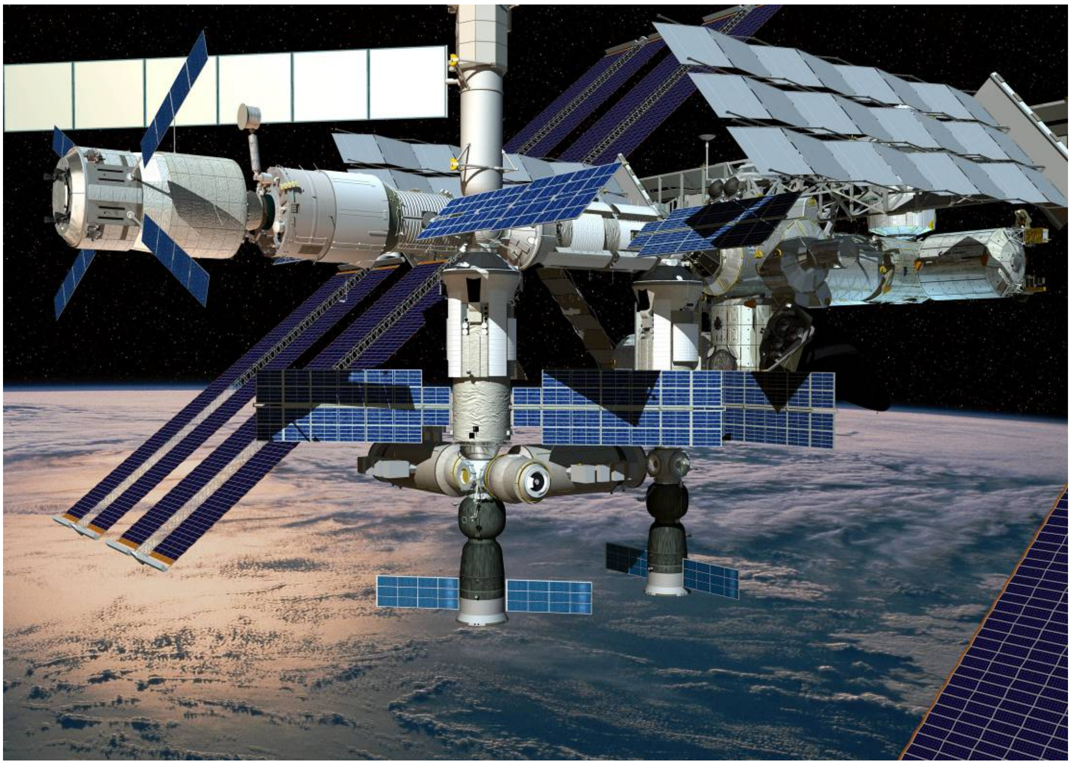
When attached to the station, the ATV remains independent in terms of its own electrical power, thermal control and data management.



At the planned moment, predefined in the frame of the ISS/ATV combined operations involving ATVCC and MCCs, the space station can determine a required ATV operational mode by sending a set of commands in order to use the ATV propulsion system, conduct the transfer of propellants or carry out the cargo-related operations. All the operations comply with the ISS operations plan determined by the control centres in Moscow and Houston.

During cargo operations by IVA in the Pressurized Module (dry cargo transfer, water or gas delivery, waste transfer), the ATV remains in dormant mode. It is re-activated (under ATV-CC control) to conduct re-boost and attitude control operations that can be performed in several increments throughout the attached phase. Each increment can last up to 12 hours. The ATV propulsion system is controlled directly by the ISS guidance, navigation and flight control software. Orbital corrections are provided by the ATV main engines. The attitude control manoeuvres are maintained by the attitude control thrusters.

The propellant transfer (refuelling) operations are also controlled directly by the ISS and can be conducted in one or several increments. The fuel and oxidizer are loaded in successive sequences including necessary leak checks and line purging conducted upon the ISS commands. Those operations require ATV in a specific active mode in parallel or not with ISS attitude control by ATV. The ATV health status is monitored by ATV-CC.



SEPARATION AND DEPARTURE FROM THE ISS, DE-ORBITING AND ATMOSPHERIC RE-ENTRY

The ATV can remain attached to the station for a 6 month maximum period. In case of contingency declared by the ISS that requires clearing of the ISS service module docking port, the ATV is de-docked from the station and waits for a maximum period of 8 weeks before re-docking.

After completion of the mission objectives, the ATV is prepared by ATV-CC for departure, and then the ATV-CC commands the separation from ISS. After one minute of free drift, the ATV performs autonomously a fly away manoeuvre to exit the Approach Ellipsoid within around 15 minutes. Then the ATV performs a de-orbiting boost under ground control and destructive re-entry above predefined fall out areas in the oceans. The de-orbiting operations can last about 10 or 20 hours depending on the fall out areas chosen.

7.3. 'Jules Verne' Mission Constraints and Planning

ATV launch is only constrained by time and not by date. In other words, ATV can be launched on any day, at a time specific to that day. Therefore a delay in the launch count-down induces a launch slip. The delay between two consecutive launches is circa 23hr36min (i.e. launch will occur on the next day circa 24 minutes before launch time on the current day).

ATV demoflight mission profile is to perform Demoday 1, Post-ESCAPE, Demoday 2, Post ESCAPE and RDV day

Taking into account the traffic to the ISS (Progress P28, STS Columbus mission, Japanese module 1JA mission, Soyuz 15S), the minimum duration between Demoday 1 and Demo-day 2 (48 hours), Demoday 2 and RDV day (48hours) and the specific constraints on Demodays and RDV day linked to :

- β range (sun elevation on orbit plan),
- SM camera dazzling by Sun,
- VDM dazzling by the Sun,
- VDM indirect dazzling by the Sun,
- TM/TC/Video space to ground (ISS) coverage through TDRS (S-Band for TM/TC, Ku Band for video)

With a launch fixed on March, 8th, the reference planning is:

- Demonstration day 1 on 29.03.2008
- Demonstration day 2 on 01.04.2008
- Docking to ISS on 03.04.2008

8. Astrium and the ATV programme

Astrium Space Transportation, an EADS company, is ESA's selected prime contractor for the main space infrastructure elements developed in Europe, for the world renowned Ariane launch vehicle family and for the ballistic missiles for the French deterrence forces.

Beyond Columbus (successfully launch aboard the US space shuttle Atlantis on February, 7th, 2008 and docked to the ISS a few days later), Astrium Space Transportation has been priming the ATV program, without any doubts the most complex spacecraft program in the history of the European space activities. As such, Astrium Space Transportation was responsible of the following activities:

- System engineering
- Qualification and acceptance tests (on the vehicle, on test platforms…), including verification of interfaces (with the ISS, with the A5 launch system, with the ATV control centre…)
- Provision of subsystems and elements (on-board software, avionics chain and EAB, propulsion subsystem and EPB, fluidic equipment, fault tolerant computer, separation system, solar wings…)
- Development of the system operations reference and delivery of all the necessary operations products to operate the ATV control centre (users manuals, vehicle control procedures, on-board monitoring plans, ground alarms, derived parameters…)
- Design authority and engineering support at ATV Control Centre and in Les Mureaux during flight
- Vehicle integration and test
- Launch campaign
- Management of the industrial organisation throughout Europe, Russia and the United States
- Support to ESA (relationship with ISS partners…)